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Effect of NUCLEAR RADIATION on Materials at CRYOGENIC TEMPERATURES

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QUARTERLY PROGRESS REPORT

No. 9, January 1963 through March 1963

Effect of Nuclear Radiation on materials at Cryogenic Temperatures

Quarterly...

PREPARED UNDER

National Aeronautics/Space Administration (NASA Contract NASw-114)

APPROVED BY

Schwanbeck

C. A. Schwanbeck 1963 79 p

NASA CRYOGENICS
PROJECT MANAGER

5241005

5240403

~~Lockheed-Georgia Company~~ Marietta

LOCKHEED NUCLEAR PRODUCTS, A Division of Lockheed Aircraft Corporation

Marietta, Ga.

Contract: NASw-114	Code: U

FOREWORD

This quarterly report is submitted to the Office of Space Launch Vehicles of the National Aeronautics and Space Administration in accordance with the requirements of NASA Contract NASw-114.

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1 INTRODUCTION AND SUMMARY

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This report describes the progress made during the quarter, January through March 1963, on Contract NASw-114.

Preparation for in-pile testing continued with modification of the test loops and the test loop transfer system carriages.

Procedures were written outlining the method of operating test equipment which will be used in the test program.

Remote tool fabrication continued during the reporting period.

Chemical analyses of the reactor primary water indicated the presence of tungsten contamination and an investigation was undertaken to determine the source.

Data reported in Quarterly Report Number 8 was re-evaluated and is included in the current report. AUTHOR

2 EQUIPMENT

2.1 BEAM PORT SHIELD

During this period, the Plum Brook Reactor primary coolant system was operated so that experimental flow rate of coolant water to the shield could be obtained. The maximum flow rate through the shield without a test loop in the beam port was determined to be 66 gpm instead of the 80 gpm originally anticipated. The pressure drop across the shield and flow measuring equipment was 30 psi. As a result of this new maximum flow rate, another temperature distribution analysis of the front portion of the shield was obtained. A flow rate of 55 gpm was used to compensate for the fact that a lesser flow rate would be available with the test loop in the beam port. Other experiments regarding flow rate in other experimental ports in the reactor have also indicated the variations in flow rate would effect the flow in HB-2 beam port making a flow rate of 55 gpm a conservative value. Previous gamma heating measurements in the head of the test loop at low power levels indicated that the gamma heating rate used in previous analysis is also very conservative. In the later temperature analysis, heat generation rates of 6.9 and 6 watts per gram were used. The results of this analysis indicate that the maximum temperature on the outer shield will still occur on the outer surface. These temperatures are 281^{o}F, using a 6.9 watts per gram heating rate, and 267^{o}F based on a gamma heating rate of 6 watts per gram. Additional calculations were made to estimate the pressure drop through the shield. These calculations indicated a pressure drop of approximately 28 psi with a flow rate of 55 gpm and of approximately 40 psi pressure drop with a 66 gpm flow rate. Since a test loop was assumed to be inserted in the beam port for these calculations, a greater pressure drop may be expected than the value obtained experimentally. These calculations have indicated that a reduced flow rate to the beam port shield is entirely permissible. Approval was obtained from the NASA Plum Brook Safeguards Committee to change the flow rate from 80 gpm to 55 gpm, provided the minimum flow rate should be changed from 20 gpm to 40 gpm. The Project has complied with this requirement.

During the approach to power of the reactor, significant amounts of W^{187} activity appeared in the primary coolant water system. A detailed investigation has been underway since to determine the source of this activity level. One of the possibilities is that the activity may be a result of minute amounts of tungsten electrode used in an arc welding method having been deposited in the weld areas during the welding operations. This material is subsequently removed from its position on the surface of the weld areas by the errosive action of the coolant water and then activated as it passes through the reactor core as a particulate matter of colloidal dimensions, thus causing tungsten activity in the primary coolant water. Samples of the coolant water were taken before the water entered the shield, and again after it had passed through the shield, to determine any difference of activity level in the water passing through the shield. The results of this investigation gave no evidence that the activity is coming from the inner part of the shield.

The external surface of the shield was examined visually for deterioration of the nickel plating which was deposited by an electroless nickel process. The minimum thickness of the plating on all portions of the Mallory 1000 material was .005 inch. The visual examination with the unaided eye indicated no deterioration. In order to better examine the external surface for evidence of the possibility of peeling, erosion or other damage to the plating, it was decided to use a telescope and mirrors so that the external surface of the shield could be examined more extensively. With this method, all but the bottom portion and the spherical radius on the front end of the outer shield could be examined. No evidence of damage to the plating was noted. Even though there was no evidence of nickel in the water, it was decided that the possibility of erosion in the nickel plating should be further investigated. The most obvious location for erosion is in the area of the highest water velocity. Since the high velocity water passing through the annular passageways in the inner shield impinges directly on the front face of the shield plug, the plug was removed using remote handling techniques. After removal, a black deposit was observed on the front face in the vicinity of the annular passageways. The inside diameter of the deposit coincided with the inside diameter of the annular passageways. The amounts of the black deposit in the area of the inner annular passageway decreased as a function of radial difference until the outer annular passageway was reached, at which point the deposite was again heavier and again decreased as the function of radial difference. An analysis on a portion of this deposit indicated that the primary material is nickel with smaller amounts of phospherous and iron. There is no evidence of tungsten. The appearance of the phosphorus in the deposit can be explained by the fact that nickel deposited by this particular electroless process contains approximately 8-10% phosphorus in the plating. The presence of iron in the deposit may at least be partially explained by the fact that the shield plug was temporarily stored in a container in which an oxidation deposit was evident, some of which may have been deposited on the plug.

Prior to final selection of Mallory 1000 material for the shield and also the electroless nickel process for the plating on the shield, separate tests were conducted by the P. R. Mallory Company and Lockheed to determine the effects of hot water and saturated steam on these materials. These tests are outlined on Pages 182 and 183 of the Progress Report for the period December 1959 through September 1960. The final results of the tests as conducted by Lockheed are listed below:

Specimen Designation	Description	Test Time (hours)	Test for Nickel	Test for Tungsten
B	Mallory 1000 welded to Inconel alkaline electroless nickel plate - .002-.003" thick - Bond tested in hydrogen at 500°C.	9129	Negative	Negative
C	Mallory 1000 welded to Inconel acid electroless nickel plate - .002 to .003" thick - Bond tested in hydrogen at 500°C.	9129	Negative	Negative

Specimen Designation	Description	Test Time (hours)	Test for Nickel	Test for Tungsten
2	Inconel welded to Mallory 1000 with Inconel A rod specimen plated with nickel - .002 to .005" thick.	9984	Negative	Negative
3	Test blocks of Mallory 1000. Overlapped and fastened. Assembly plated with .003 to .005" nickel.	5806	Negative	Negative

NOTES:

1. The effect of exposure on the original black surface of specimen B and C is slight.
2. Test specimen 2 is coated with a light brown stain while specimen 3 shows negligible effects.
3. The dilution limit for nickel and tungsten tests is 1:300,000 and 1:10,000, respectively.

In addition to the above outlined investigation, an activation analysis of the shield was completed to determine the activity level of the beam port shield. This was done in the event that it would become necessary to remove the shield as a result of damage to the plating or for some other cause. The results of this activation analysis are outlined below:

Activation dose rates from the Mallory 1000 in the HB-2 shield have been estimated considering the geometry shown in Figure 1. The assumed composition of the Mallory 1000 was:

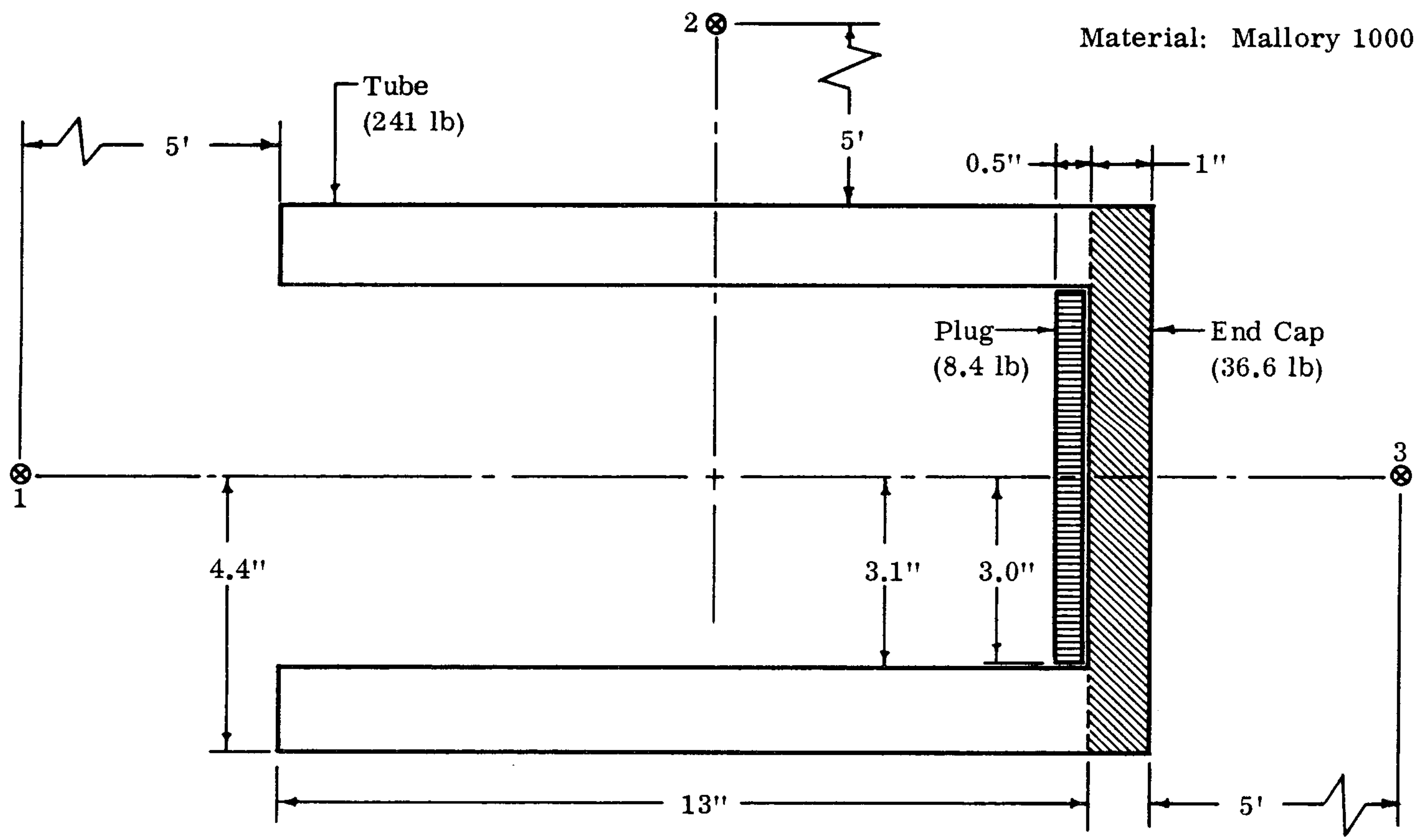


FIGURE 1 SHIELD CALCULATIONAL GEOMETRY

Element	Weight Percent
W	90
Cu	6
Ni	4

The shield was assumed to be in place while the reactor was operated as follows:

Power (MW)	Time at Power (hrs)
15	48
25	27
35	24
40	52
45-49	70 (linear increase)
55	89
60	15

For preliminary calculations, the time-averaged power was determined from the above cycle to be 41 MW. A constant power operation at 41 MW was assumed for the total reactor operating time. This assumption was made for preliminary analyses only and it was recognized that this could lead to errors in calculated dose rates, depending on the half life of the reaction product. This assumption results in calculated values lower than those that would be observed, with the error increasing with decreasing half life of the reaction product.

Possible reactions eliminated because of short half life (dose rates at 24 hours decay are desired), low isotopic composition, low cross section, or a combination of these factors were:

$Ni^{58}(n, 2n)Ni^{57}$
$Ni^{62}(n, \gamma)Fe^{59}$
$Ni^{64}(n, \gamma)Ni^{65}$
$Cu^{63}(n, \gamma)Co^{60}$
$Cu^{65}(n, p)Ni^{65}$
$Cu^{65}(n, \gamma)Cu^{66}$
$W^{180}(n, \gamma)W^{181}$

Preliminary estimates were made of activity per unit flux for the assumed constant power irradiation for the following reactions, in order to determine those producing significant activities at 24 hours decay time:

$$Ni^{58}(n, p)Co^{58m}$$
$$Ni^{58}(n, p)Co^{58}$$
$$Ni^{60}(n, p)Co^{60}$$
$$Cu^{63}(n, \gamma)Cu^{64}$$
$$W^{186}(n, \gamma)W^{187}$$

The controlling reaction was $W^{186}(n, \gamma)W^{187}$, with the nearest competitor, $Cu^{63}(n, \gamma)Cu^{64}$, being over two orders of magnitude lower. Accordingly, the dose rates from the shield were calculated on the basis of constant power operation at 41 MW considering only the tungsten reaction. Average were computed for each of the three segments (tube, end cap, plug) of the shield utilizing Figure 57 as contained in Quarterly Progress Report No. 1, December 1959 through September 1960, Lockheed Nuclear Products Report NR-115, and assuming the same thermal flux attenuation with distance away from the reactor as occurs in the water surrounding the Bulk Shielding Reactor. The resultant flux values for 41 MW are:

Segment	Average Thermal Flux
Tube	2.4×10^{12}
End Cap	2.1×10^{13}
Plug	4.3×10^{12}

The decay scheme assumed for W^{187} is shown in Figure 2, based on data set forth in Strominger, D., et al., Table of Isotopes, Reviews of Modern Physics, Vol. 30, Number 2, Part 2, (April 1958):

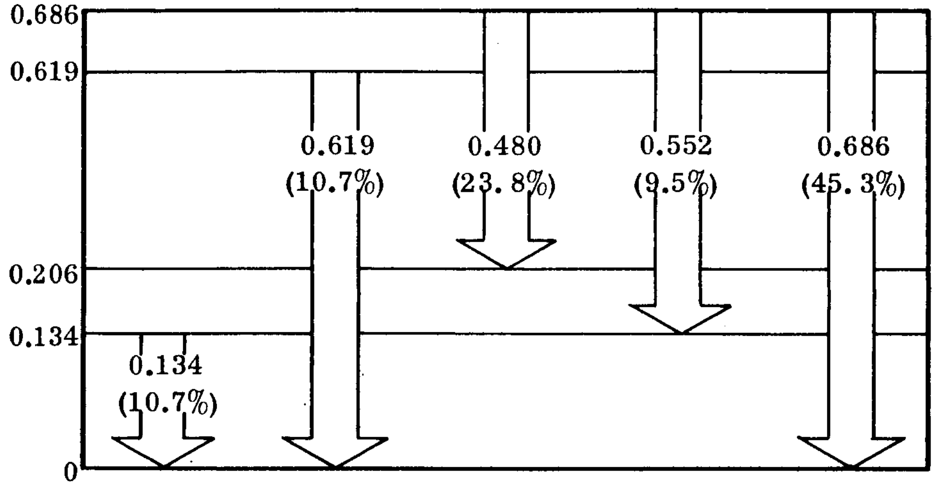


FIGURE 2 DECAY SCHEME OF W^{187}, HALF LIFE = 24 HOURS

The resulting dose rates for the three points indicated in Figure 1 are:

Point	Gamma Dose Rate (r/hr) - 24 Hours Decay
1	5×10^3
2	2×10^3
3	6×10^3

In calculating the dose rates an approximation for the self-shielding effect within the shield was used by converting the volume source to an equivalent surface isotropic source.

Since the half life of W^{187} is 24 hours, the calculated dose rates for constant 41 MW operation are low since the W^{187} will reach a saturation value during operation in the 55-60 MW level. To account for this factor the dose rates should be increased by about 1.3, yielding the dose rates shown below:

Point	Gamma Dose Rate (r/hr) - 24 Hours Decay
1	7×10^3
2	3×10^3
3	8×10^3

2.2 TEST LOOPS

During the process of checking out the transfer system and the test loops, the test loops were inserted into both the hot cave port and the reactor beam port, with no apparent difficulty. However, on removal, the test loop head covers were damaged as the test loop passed through the chevron seals in both the hot cave and the reactor beam ports. In this design, test loop head covers served two purposes; namely, to form a sealing surface for the helium seal on the front of the test loop head and to provide a smooth and uniform end for the test loop so that it could be inserted easily through the seal in either the hot cave or the beam port. In the removal operation, the friction between the seal and the test loop head cover caused cover deformation which resulted in breaking the bolts securing the cover assembly to the test loop head assembly. Immediate steps were taken to redesign and modify the cover assemblies. The new design is a cover which is semi-permanently attached to the head bolt flange on the head assembly. The front of this cover is now open but it provides a radius on the end for ease in inserting the test loop into the beam port or hot cave seals. The front helium cover seal plate is now a separate detail. This new design allows additional flexibility in that adjustment to any bolt holding the helium seals in place may be made without removing any covers.

Inserts in the shield assembly used to position the test loop in the inner shield also had a tendency to score portions of the test loop head covers and test loop body. In order to alleviate this situation, it was decided to hard chrome plate the new cover assemblies to a diameter approximately .0010 oversize so that this chrome plating would not allow the remainder of the test loop to ride on the inserts. It is expected that this hard chromed plating will not score in the insertion and removal processes.

Another design modification made at this time to facilitate the removal of the ten head bolts was the addition of 3/16" hex inserts into the socket head of the bolts. The length of these inserts is such that the end now extends nearer to the front end of the test loop, enabling the operator to visually locate the socket onto the head section and thus facilitate removal or insertion of the bolts.

2.3 REMOTE HANDLING EQUIPMENT

The bridge and cart, associated with the airlock, were received and installed in their respective positions at Plum Brook. Final checkout of this equipment will be made upon receipt of the test loop transfer cask.

The power driven test loop tongs designed to handle the test loop in the hot cell area were received and checked out but final remote installation has not been accomplished.

A Weldmatic spot welding machine is being considered for use in the hot cave for remote welding of the thermocouple leads on the instrumented specimen to the thermocouple leads installed in the test loops. Results of tests conducted to determine the adequacy of this machine to meet requirements for this application appear favorable. Final results will not be obtainable until it is determined if the machine can be adapted to remote operation, which is necessary to make these welds. The power supply will be positioned outside the hot cave with special long leads to the welding head entering into the hot cave by way of one of the spare conduits located in the hot cave walls.

The test loop transfer cask still remains in the fabrication phase since the vendor has had difficulty in the lead pouring phase of the operation. The problem has been that voids form adjacent to the stainless steel bulkheads of the cask as the lead cools. The contractor is presently trying to repair these voids and insure shielding integrity by packing 200 mesh pulverized lead into these areas. Results of this attempt to eliminate the problem appear favorable at this writing but are still inconclusive. A 26 curie Ir^{192} gamma source was used in testing for radiation leakage. As a matter of comparison, a level of 0.5 mr/hr was obtained at the surface of the cask through eight inches of lead using this source. When the source was moved to one of the void areas which had been filled with the 200 mesh pulverized lead, a 5-6 mr/hr reading was obtained. In the areas where this process has not been attempted yet, a level in excess of 1000 mr/hr was indicated. A maximum level of 10 mr/hr at contact in the eight inches thick lead portion of the cask has been given as a specification to the contractor. This value is considered sufficiently conservative in that no problems of excessive radiation level are envisioned at this time.

2.4 SAMPLE CHANGE SYSTEM

Neoprene seat rings installed in the 6" sliding gate valve used as a seal on the beam port showed indications of cracking shortly after the reactor primary coolant system was operated. The seat rings on which the reactor pressure was applied also showed extensive distortion under pressure. The valve was dismantled and the seat rings removed from this valve. The seat rings were replaced with those from the 6" valve normally positioned in the hot cave. Upon removal, it was noted that the neoprene was damaged on both the external and internal faces and that the inner seat ring, against which there is no normal pressure, was bowed. This set of seat rings was returned to the vendor for evaluation and explanation of the cause of the failure. The ensuing report of the vendor indicated that it was the failure of the bond between the steel plate inside the seat ring and the neoprene. No assurances could be obtained from the contractor to the effect that this was not present in either the rings now in use or in others which would be purchased in the future. It was then determined that polyurethane material should be investigated for this purpose. To facilitate testing of the new material, the 6" valve was removed from the hot cave and sent to the vendor so that new materials could be installed in this valve and then tested. The natural rubber rings were more readily available and were tested first. These tests were followed by tests of polyurethane seat rings. A summary of these tests are listed below:

Material	Cycles	Δp Across Face of Valve (psi)	Leakage
Natural Rubber	470	0	0
Natural Rubber	100	0 (seat dry)	0
Natural Rubber	1665	65	0
Natural Rubber	100	200	0
Cast Polyurethane	20	160-175	0
Cast Polyurethane	540	60-65	0
Cast Polyurethane	100	200	0

The polyurethane seat rings showed a distinct advantage for this purpose in that they did not distort under the pressure exerted by the gate on the valve. As a result of these tests, it was decided to use the polyurethane because of its stability as well as its lubricity. Permission was requested of NASA for the use of this material and approval was granted.

In a checkout phase of the sample change system, the test loop was inserted into the beam port against the pressure exerted by the reactor primary water system. During this phase of the operation, it was noted that it was progressively more difficult to insert the test loop and an investigation was made to determine the cause. It was noted that the worm and worm gear used to drive the lead screw which in turn moved the test loop into the beam port were being damaged. The material used in the worm gear was phosphor-bronze and the material in the worm was type 419 stainless steel. Further investigations indicated that the rails on which the rollers on the yoke assembly rolled were also damaged due to the excessive compressive force exerted on them. The trunions on the test loop are located in the yoke assembly and it is the yoke assembly that transmits the force to drive the test loop into the beam port. Upon disassembly of the test loop carriage, it was noted that the bronze bushing inserts in the stainless steel rollers were likewise damaged, being deformed by the excessive compressive loads.

A test was set up in order to determine the reason for the damage and also the reason for the excessive loads. In order to conduct this test, another carriage assembly was used. The journal type bearing rollers on the yoke assembly were replaced with ordinary steel cam followers. In order to simulate the load imposed by the pressure of the primary coolant system on the test loop, the test loop was replaced by a hydraulic cylinder with a variable pressure relief valve installed at the discharge of the cylinder. A dynamometer to measure the load on both hydraulic cylinder and the yoke assembly was included in the linkage. The relief valve was set so that a load of approximately 5000 pounds was exerted on the yoke assembly. After operation of the drive mechanism against this opposing load, the carriage was disassembled and inspected for damage. The worm gear showed some evidence of damage and the rails on which the yoke assembly cam followers rolled also showed evidence of compressive damage. The cam followers, however, were not deformed or damaged in any way. The results of this test indicated that other materials must be installed as wear surfaces in the carriage assembly and immediate steps were taken to make these modifications in design of both the carriage and carriage assembly. The carriages were redesigned so that the upper insert would have a greater bearing strength. The journal bearings on the yoke assembly were replaced with stainless steel cam followers. The upper insert of the test loop on which these cam followers roll was replaced with 17-4 precipitation hardening steel, which subsequently was heat treated to obtain a hard wearing surface.

It was decided to remove material from the bottom wear surfaces and install a 17-4 precipitation hardening steel insert in this position also. This insert is bolted onto the carriage with bolts from the bottom of the carriage. This insert is also hardened. 17-4 Ph steel heat treated to Rc-40 was substituted for the phosphor-bronze on the worm gear. The modifications to the carriages have now been completed. All material has been received and assembly has begun. One (1) test loop carriage is completely assembled. A simulated test to exert loading force on all members of the carriage will again be conducted to be sure that no other inherent problem remains to be solved.

3 REFRIGERATION SYSTEM

The helium refrigeration system has not been operated during this reporting period. Formal training for personnel who reported for duty since the last training period is being conducted, with the expectation that operation of the refrigeration system will take place in the near future in order to give practical operational training to these personnel. The preliminary steps necessary to get the refrigeration system functioning again are also presently in progress.

4 TEST DATA

The test data previously published have been further studied to evaluate their reliability and are republished here in an amplified form to provide a single source for complete test results.

4.1 ALUMINUM ALLOYS

The mechanical properties at $540^{o}R$ and $30^{o}R$ obtained from the screening program testing of the several aluminum alloys are contained in the following tables.

The room temperature ($540^{o}R$) ultimate tensile strength and 0.2% offset yield strength results for the alloys obtained from the miniature specimens used in this program were generally slightly lower than the results obtained from Standard ASTM E8-57T specimens and reported in the Pedigree Report (Lockheed Nuclear Products Report ER-5542, February 1962), but are in all cases within 12-1/2% of those reported values which confirms the validity of tensile results obtained from miniature specimens failed in a horizontal plane.

One apparent, and as yet unexplained, anomaly in the test results is a reported reduction in yield strength of 37-1/2% at $30^{o}R$ for aluminum alloy 1099 coupled with an increase in tensile strength by a factor of 2-1/3. A metallographic investigation is being undertaken in an effort to explain these apparently inconsistent data and the results will be reported at a later date.

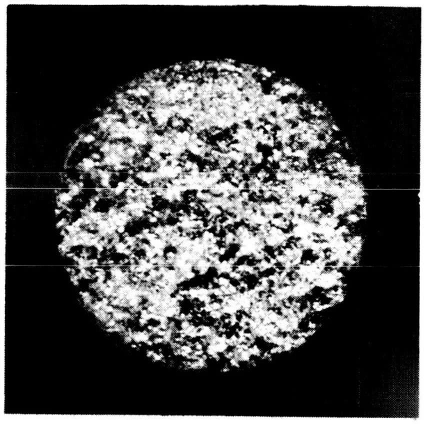
Alloy 2219-T87 exhibits an apparent notch sensitivity at cryogenic temperatures as evidenced by a reduction of some 12% of its ultimate tensile strength on tensile notch samples at $30^{o}R$.

The remainder of the aluminum alloys behaved about as expected and agreement of these test results with available literature on cryogenic testing is good.

The consistency and reproducibility of the testing methods used is demonstrated by the degree of agreement of test results on separate samples of the same alloy. With the exception of Alloy 1099, an extremely low strength alloy, where minor errors of measurement or calibration have a disproportionate influence on test results, and the casting alloys, which usually have rather erratic tensile properties due to internal cavities normally present to a degree as micro-porosity or gross defects, ultimate tensile strength, for example, in most sets of five samples fall within a 12-1/2% scatter band.

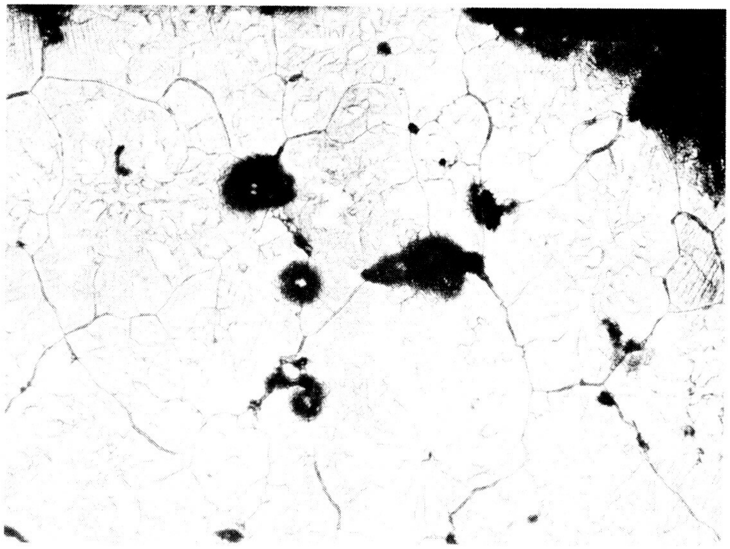
Photographs in Figure 3 show casting porosity, occurring in Aluminum Alloy X250, on macroscopic and microscopic levels. This condition, which is common in as-cast materials, reduces reproducibility in tensile test results by causing unmeasurable variations in effective cross-sectional area.

The speed of testing was controlled by the speed of the actuating hydraulic pump. The pump speed required to maintain an acceptable test rate was determined by manually marking the stress diagram at 10 second intervals during the portion of the test where the sample exhibited elastic behavior. In the case of tensile testing, the strain rate was held between 0.003 and 0.006 in/in/min, with a frequency of rate checks of approximately 30%. In tensile notch testing, since strain is not recorded, the stress rate was held between 45,000 and 90,000 psi/min with a frequency of rate checks of approximately 25%.



Fractured surface of failed tensile sample, X250 Alluminum Alloy, tested at 30°R. Fracture shows evidence of macroscopic porosity covering approximately 20% of cross-sectional area.

X 12



Keller's Etch

X 100

Longitudinal section of failed tensile sample, X250 aluminum alloy tested at 30°R, in vicinity of fracture. Section shows evidence of microporosity. Fracture at top of photograph.

FIGURE 3 MACROGRAPH AND MICROGRAPH OF FAILED ALUMINUM ALLOY X250 SPECIMEN

TABLE 1

TENSILE TEST OF MINIATURE ROUND
ALUMINUM ALLOY 1099 SPECIMENS

Alloy	Aluminum 1099	Specification	Vendor
Alloy Code	8 Ba	Heat No.	199352
Condition	H-14	Size	0.125" Diameter
Orientation	Longitudinal	Figure No.	5 ER-5848

LNP Data

Specimen Number	Test Temp. (^{o}R)	F_{tu} (psi)	F_{ty} 0.2% Offset (psi)	Elongation (% in 1/2")
8 Ba 1	540	11,700	11,000	20
8 Ba 2	540	13,300	12,600	20
8 Ba 7	540	14,000	13,400	20
8 Ba 27	540	12,600	11,800	18
8 Ba 34	540	14,500	13,500	20
Average		13,200	12,500	20
Scatter		22%	20%	10%
8 Ba 36	30	33,000	8,200	56
8 Ba 37	30	31,500	7,900	60
8 Ba 39	30	30,000	6,000	54
8 Ba 40	30	30,000	8,000	64
8 Ba 43	30	32,000	8,800	58
Average		31,300	7,800	58
Scatter		9.5%	36%	15%
Net Change, F_{tu} at $30^{o}R$				+137%
Net Change, F_{ty} at $30^{o}R$				-37.6%
Net Change, Elongation at $30^{o}R$				+190%

TABLE 2

TENSILE TEST OF MINIATURE ROUND NOTCHED ALUMINUM ALLOY 1099 SPECIMENS

Alloy	Aluminum 1099	Specification	Vendor
Alloy Code	8 Ba	Heat No.	199352
Condition	H-14	Size	0.125" Diameter
Orientation	Longitudinal	Figure No.	1 NR-122

LNP Data

Specimen Number	Test Temp. (^{o}R)	F_{tu} (psi)
8 Ba 3	540	16,200
8 Ba 7	540	16,400
8 Ba 14	540	15,200
8 Ba 18	540	15,950
8 Ba 26	540	16,800
Average		16,100
Scatter		9.5%
8 Ba 28	30	47,200
8 Ba 42	30	45,800
8 Ba 44	30	47,800
8 Ba 45	30	44,800
8 Ba 57	30	47,800
Average		46,700
Scatter		6.3%
Net Change, F_{tu} Tensile Notch, at $30^{o}R$		+190%

TABLE 3

TENSILE TEST OF MINIATURE ROUND ALUMINUM ALLOY 2014 SPECIMENS

Alloy	Aluminum 2014	Specification	AMS 4029
Alloy Code	1 Ba	Heat No.	747-461
Condition	T-651	Size	0.125" Diameter
Orientation	Longitudinal	Figure No.	5 ER-5848

LNP Data

Specimen Number	Test Temp. (^{o}R)	F_{tu} (psi)	F_{ty} 0.2% Offset (psi)	Elongation (% in 1/2")
1 Ba 13	540	69,500	64,200	12
1 Ba 35	540	62,400	57,500	12
1 Ba 46	540	64,800	59,600	14
1 Ba 47	540	64,600	59,300	12
1 Ba 48	540	65,600	61,100	12
Average	540	65,400	60,000	12
Scatter		10%	10%	14%

TABLE 4

TENSILE TEST OF MINIATURE ROUND NOTCHED ALUMINUM ALLOY 2014 SPECIMENS

Alloy	Aluminum 2014	Specification	AMS 4029
Alloy Code	1 Ba	Heat No.	747-461
Condition	T-651	Size	0.125" Diameter
Orientation	Longitudinal	Figure No.	1 NR-122

LNP Data

Specimen Number	Test Temp. (^{o}R)	F_{tu} (psi)
1 Ba 15	540	80,500
1 Ba 16	540	76,700
1 Ba 18	540	80,700
1 Ba 19	540	79,300
1 Ba 27	540	80,000
Average	540	79,500
Scatter		4.7%
1 Ba 54	30	100,100
1 Ba 55	30	98,800
1 Ba 57	30	101,500
1 Ba 58	30	101,900
1 Ba 61	30	102,000
Average	30	100,900
Scatter		4%
Net Change, F_{tu} Tensile Notch at 30^{o}R		+26.9%

TABLE 5

TENSILE TEST OF MINIATURE ROUND ALUMINUM ALLOY 2024 SPECIMENS

Alloy	Aluminum 2024	Specification	AMS-4037-E
Alloy Code	7 Ba	Heat No.	747-441
Condition	T-351	Size	0.125" Diameter
Orientation	Longitudinal	Figure No.	5 ER-5848

LNP Data

Specimen Number	Test Temp. (^{o}R)	F_{tu} (psi)	F_{ty} 0.2% Offset (psi)	Elongation (% in 1/2")
7 Ba 1	540	67,300	50,500	22
7 Ba 7	540	67,200	50,000	20
7 Ba 17	540	68,100	50,400	22
7 Ba 23	540	65,200	49,000	22
7 Ba 40	540	66,400	50,300	24
Average	540	66,800	50,000	22
Scatter		12 %	3 %	20%
7 Ba 28	30	104,200	74,800	22
7 Ba 29	30	98,100	76,900	*
7 Ba 32	30	92,700	64,500	20
7 Ba 36	30	93,800	66,000	22
7 Ba 39	30	95,400	67,100	18
Average	30	96,800	69,900	20
Scatter		11 %	17%	20%
Net Change, F_{tu} at 30^{o}R				+45%
Net Change, F_{ty} at 30^{o}R				+40%
Net Change, Elongation at 30^{o}R				0

* Fractured faces distorted by compression of sample after failure but before measurement of elongation.

TABLE 6

TENSILE TEST OF MINIATURE ROUND NOTCHED ALUMINUM ALLOY 2024 SPECIMENS

Alloy	Aluminum 2024	Specification	AMS-4037E
Alloy Code	7 Ba	Heat No.	747-441
Condition	T-351	Size	0.125" Diameter
Orientation	Longitudinal	Figure No.	1 NR-122

LNP Data

Specimen Number	Test Temp. (^oR)	F_{tu} (psi)
7 Ba 4	540	68,600
7 Ba 5	540	62,000
7 Ba 8	540	73,600
7 Ba 10	540	74,600
7 Ba 11	540	73,800
Average	540	70,500
Scatter		18%
7 Ba 12	30	98,000
7 Ba 20	30	99,100
7 Ba 24	30	102,000
7 Ba 38	30	100,300
7 Ba 42	30	83,300
Average	30	96,500
Scatter		20%
Net Change, F_{tu} Tensile Notch at 30^oR		+37%

TABLE 7

TENSILE TEST OF MINIATURE ROUND ALUMINUM ALLOY 2219 SPECIMENS

Alloy	Aluminum 2219	Specification	Vendor
Alloy Code	2 Ba	Heat No.	124-481
Condition	T-87	Size	0.125" Diameter
Orientation	Longitudinal	Figure No.	5 ER-5848

LNP Data

Specimen Number	Test Temp. (^oR)	F_{tu} (psi)	F_{ty} 0.2% Offset (psi)	Elongation (% in 1/2")
2 Ba 41	540	63,500	51,400	14
2 Ba 45	540	62,700	51,400	*
2 Ba 50	540	63,100	51,000	14
2 Ba 53	540	62,400	50,600	14
Average	540	62,900	51,100	14
Scatter		1.7%	3.5%	0
2 Ba 30	30	95,700	66,900	18
2 Ba 32	30	96,500	68,400	16
2 Ba 34	30	95,200	67,100	14
2 Ba 35	30	95,600	69,000	20
2 Ba 36	30	96,400	70,000	18
Average	30	95,900	68,300	17
Scatter		1.35%	4.5%	30%
Net Change, F_{tu} at 30^oR				+52%
Net Change, F_{ty} at 30^oR				+33%
Net Change, Elongation at 30^oR				+20%

* Fractured faces distorted by compression of sample after failure but before measurement of elongation.

TABLE 8

TENSILE TEST OF MINIATURE ROUND NOTCHED
ALUMINUM ALLOY 2219 SPECIMENS

Alloy	Aluminum 2219	Specification	Vendor
Alloy Code	2 Ba	Heat No.	124-481
Condition	T-87	Size	0.125" Diameter
Orientation	Longitudinal	Figure No.	1 NR-122

LNP Data

Specimen Number	Test Temp. (^{O}R)	F_{tu} (psi)
2 Ba 31	540	114,200
2 Ba 37	540	109,400
2 Ba 38	540	110,800
2 Ba 40	540	112,700
2 Ba 42	540	112,400
Average	540	111,900
Scatter		4%
2 Ba 43	30	99,300
2 Ba 44	30	102,000
2 Ba 49	30	89,400
2 Ba 52	30	98,700
2 Ba 54	30	101,400
Average	30	98,200
Scatter		13%
Net Change, F_{tu} Tensile Notch at 30^{O}R		-12%

TABLE 9

TENSILE TEST OF MINIATURE ROUND ALUMINUM ALLOY 5083 SPECIMENS

Alloy	Aluminum 5083	Specification	MIL-H-173 58B
Alloy Code	3 Ba	Heat No.	124-461
Condition	H-321	Size	0.125" Diameter
Orientation	Longitudinal	Figure No.	5 ER-5848

LNP Data

Specimen Number	Test Temp. (^oR)	F_{tu} (psi)	F_{ty} 0.2% Offset (psi)	Elongation (% in 1/2")
3 Ba 4	540	47,000	31,800	12
3 Ba 5	540	46,000	31,300	10
3 Ba 6	540	45,600	31,900	12
3 Ba 7	540	46,500	33,200	12
3 Ba 8	540	46,800	32,700	10
Average	540	46,400	32,200	11
Scatter		3%	5.9%	20%
3 Ba 12	30	93,500	43,600	*
3 Ba 34	30	87,700	43,000	*
3 Ba 38	30	88,700	41,700	21
3 Ba 39	30	93,000	42,000	26
3 Ba 42	30	83,100	39,400	*
Average	30	89,200	41,900	23-1/2
Scatter		12%	10%	21%
Net Change, F_{tu} at 30^oR				+92%
Net Change, F_{ty} at 30^oR				+30%
Net Change, Elongation at 30^oR				+114%

* Broke outside gage mark.

TABLE 10

TENSILE TEST OF MINIATURE ROUND NOTCHED
ALUMINUM ALLOY 5083 SPECIMENS

Alloy	Aluminum 5083	Specification	MIL-H-17358B
Alloy Code	3 Ba	Heat No.	124-461
Condition	H-321	Size	0.125" Diameter
Orientation	Longitudinal	Figure No.	1 NR-122

LNP Data

Specimen Number	Test Temp. (^{o}R)	F_{tu} (psi)
3 Ba 15	540	54,700
3 Ba 16	540	54,990
3 Ba 17	540	54,900
3 Ba 18	540	55,950
3 Ba 19	540	55,200
Average	540	55,100
Scatter		2.3%
3 Ba 1	30	74,500
3 Ba 21	30	69,800
3 Ba 22	30	74,100
3 Ba 20	30	75,200
Average	30	73,400
Scatter		7.4%
Net Change, F_{tu} Tensile Notch at $30^{o}R$		+33%

TABLE 11

TENSILE TEST OF MINIATURE ROUND
ALUMINUM ALLOY 5086 SPECIMENS

Alloy	Aluminum 5086	Specification	MIL-A-19070-A
Alloy Code	11 Ba	Heat No.	RK-7948
Condition	H-321	Size	0.125" Diameter
Orientation	Longitudinal	Figure No.	5 ER-5848

LNP Data

Specimen Number	Test Temp. (^{o}R)	F_{tu} (psi)	F_{ty} 0.2% Offset (psi)	Elongation (% in 1/2")
11 Ba 30	540	44,400	31,100	*
11 Ba 31	540	45,800	32,800	10
11 Ba 32	540	44,500	32,100	10
Average	540	44,900	32,000	10
Scatter		3.1%	5.3%	0

* Fractured faces distorted by compression of sample after failure but before measurement of elongation.

TABLE 12

TENSILE TEST OF MINIATURE ROUND NOTCHED ALUMINUM ALLOY 5086 SPECIMENS

Alloy	Aluminum 5086	Specification	MIL-A-19070-A
Alloy Code	11 Ba	Heat No.	RK-7948
Condition	H-321	Size	0.125" Diameter
Orientation	Longitudinal	Figure No.	1 NR-122

LNP Data

Specimen Number	Test Temp. (^{o}R)	F_{tu} (psi)
11 Ba 15	540	52,600
11 Ba 16	540	53,600
11 Ba 17	540	53,300
11 Ba 18	540	52,600
11 Ba 19	540	52,400
Average	540	52,900
Scatter		2.3%
11 Ba 20	30	70,700
11 Ba 21	30	58,900
11 Ba 22	30	75,600
11 Ba 23	30	68,400
11 Ba 24	30	68,700
Average	30	68,400
Scatter		17.3%
Net Change, F_{tu} Tensile Notch at $30^{o}R$		+29%

TABLE 13

TENSILE TEST OF MINIATURE ROUND ALUMINUM ALLOY 5456 SPECIMENS

Alloy	Aluminum 5456	Specification	MIL-A-19842-B
Alloy Code	5 Ba	Heat No.	124-351
Condition	H-321	Size	0.125" Diameter
Orientation	Longitudinal	Figure No.	5 ER-5848

LNP Data

Specimen Number	Test Temp. (^oR)	F_{tu} (psi)	F_{ty} 0.2% Offset (psi)	Elongation (% in 1/2")
5 Ba 10	540	51,300	34,800	10
5 Ba 11	540	49,200	34,100	10
5 Ba 14	540	48,500	34,000	12
5 Ba 30	540	49,700	33,800	10
5 Ba 31	540	49,400	32,600	12
Average	540	49,600	33,900	11
Scatter		5.6%	6.4%	20%
5 Ba 1	30	90,200	45,100	16
5 Ba 3	30	91,300	44,700	18
5 Ba 4	30	92,900	45,100	*
5 Ba 6	30	94,200	44,800	22
5 Ba 7	30	92,300	45,100	22
Average	30	92,200	44,900	19
Scatter		4.3%	1%	32%
Net Change, F_{tu} at 30^oR				+ 86%
Net Change, F_{ty} at 30^oR				+ 32%
Net Change, Elongation at 30^oR				+ 42%

* Fractured faces distorted by compression of sample after failure but before measurement of elongation.

TABLE 14

TENSILE TEST OF MINIATURE ROUND NOTCHED ALUMINUM ALLOY 5456 SPECIMENS

Alloy	Aluminum 5456	Specification	MIL-A-19842-B
Alloy Code	5 Ba	Heat No.	124-351
Condition	H-321	Size	0.125" Diameter
Orientation	Longitudinal	Figure No.	1 NR-122

LNP Data

Specimen Number	Test Temp. (^oR)	F_{tu} (psi)
5 Ba 15	540	59,700
5 Ba 16	540	59,600
5 Ba 17	540	58,500
5 Ba 19	540	60,400
5 Ba 20	540	59,800
Average	540	59,600
Scatter		3.2%
5 Ba 22	30	70,400
5 Ba 25	30	67,400
5 Ba 24	30	69,100
5 Ba 26	30	68,900
5 Ba 27	30	70,400
Average	30	69,200
Scatter		4.5%
Net Change, F_{tu} Tensile Notch at 30^oR		+16%

TABLE 15

TENSILE TEST OF MINIATURE ROUND
ALUMINUM ALLOY 6061 SPECIMENS

Alloy	Aluminum 6061	Specification	QQA327B
Alloy Code	12 Ba	Heat No.	75762A
Condition	T-6	Size	0.125" Diameter
Orientation	Longitudinal	Figure No.	5 ER-5848

LNP Data

Specimen Number	Test Temp. (^{o}R)	F_{tu} (psi)	F_{ty} 0.2% Offset (psi)	Elongation (% in 1/2")
12 Ba 6	540	53,200	40,400	16
12 Ba 8	540	41,600	38,500	20
12 Ba 10	540	44,100	40,600	20
12 Ba 11	540	44,100	40,300	20
12 Ba 12	540	43,600	40,700	20
Average	540	43,300	40,100	20
Scatter		5.8%	5.5%	20%
12 Ba 1	30	72,300	55,600	30
12 Ba 2	30	68,600	51,200	23
12 Ba 3	30	67,800	51,000	25
12 Ba 4	30	66,200	49,700	28
12 Ba 5	30	66,000	44,600	30
Average	30	68,200	50,400	27
Scatter		9.2%	22%	26%
Net Change, F_{tu} at 30^{o}R				+57%
Net Change, F_{ty} at 30^{o}R				+25%
Net Change, Elongation at 30^{o}R				+30%

TABLE 16

TENSILE TEST OF MINIATURE ROUND NOTCHED ALUMINUM ALLOY 6061 SPECIMENS

Alloy	Aluminum 6061	Specification	QQA327B
Alloy Code	12 Ba	Heat No.	75762A
Condition	T-6	Size	0.125" Diameter
Orientation	Longitudinal	Figure No.	1 NR-122

LNP Data

Specimen Number	Test Temp. (^{o}R)	F_{tu} (psi)
12 Ba 55	540	57,300
12 Ba 58	540	54,300
12 Ba 59	540	57,700
12 Ba 63	540	54,600
12 Ba 64	540	57,900
Average	540	56,400
Scatter		6.4%
12 Ba 67	30	74,600
12 Ba 68	30	71,200
12 Ba 72	30	73,800
12 Ba 74	30	72,400
12 Ba 77	30	72,900
Average	30	72,900
Scatter		4.6%
Net Change, F_{tu} Tensile Notch at 30^{o}R		+29%

TABLE 17

TENSILE TEST OF MINIATURE ROUND
ALUMINUM ALLOY 7178 SPECIMENS

Alloy	Aluminum 7178	Specification	MIL-A-9180A
Alloy Code	10 Bb	Heat No.	747-711
Condition	T-651	Size	0.125" Diameter
Orientation	Longitudinal	Figure No.	5 ER-5848

LNP Data

Specimen Number	Test Temp. (^{o}R)	F_{tu} (psi)	F_{ty} 0.2% Offset (psi)	Elongation (% in 1/2")
10 Bb 134	540	88,200	81,000	12
10 Bb 138	540	87,800	79,500	12
10 Bb 152	540	86,100	80,000	12
10 Bb 153	540	88,200	81,200	12
10 Bb 154	540	88,500	81,100	10
Average	540	87,800	80,600	12
Scatter		2.9%	2.1%	20%
10 Bb 157	30	131,400	110,600	12
10 Bb 158	30	128,000	107,700	10
10 Bb 159	30	129,300	107,300	10
10 Bb 161	30	128,600	108,900	10
10 Bb 162	30	126,900	104,000	8
Average	30	128,800	107,700	10
Scatter		3.4%	6%	40%
Net Change, F_{tu} at 30^{o}R				+47%
Net Change, F_{ty} at 30^{o}R				+34%
Net Change, Elongation				-17%

TABLE 18

TENSILE TEST OF MINIATURE ROUND NOTCHED ALUMINUM ALLOY 7178 SPECIMENS

Alloy	Aluminum 7178	Specification	MIL-A-9180A
Alloy Code	10 Bb	Heat No.	747-711
Condition	T-651	Size	0.125" Diameter
Orientation	Longitudinal	Figure No.	1 NR-122

LNP Data

Specimen Number	Test Temp. (°R)	F_{tu} (psi)
10 Bb 137	540	99,500
10 Bb 142	540	100,200
10 Bb 144	540	100,200
10 Bb 145	540	100,300
10 Bb 148	540	100,400
Average	540	100,100
Scatter	540	< 1%
10 Bb 65	30	119,700
10 Bb 62	30	119,200
Average	30	119,500
Scatter	30	< 1%
Net Change, F_{tu} Tensile Notch at 30°R		+19.4%

TABLE 19

TENSILE TEST OF MINIATURE ROUND ALUMINUM ALLOY X-250 SPECIMENS

Alloy	Aluminum X-250	Specification	Vendor
Alloy Code	4 Ba	Heat No.	E 2464A-D
Condition	T-4	Size	0.125" Diameter
Orientation	Longitudinal	Figure No.	5 ER-5848

LNP Data

Specimen Number	Test Temp. (^oR)	F_{tu} (psi)	F_{ty} 0.2% Offset (psi)	Elongation (% in 1/2")
4 Ba 8	540	58,600	31,900	20
4 Ba 9	540	60,700	32,300	24
4 Ba 10	540	58,500	33,000	20
4 Ba 25	540	43,500	30,700	**
4 Ba 26	540	58,800	33,500	22
Average	540	56,000	32,300	20
Scatter		30%	8.6%	20%
4 Ba 31*	30	42,300*	**	2
4 Ba 37*	30	46,300*	**	2
4 Ba 38*	30	42,000*	**	** *
4 Ba 29	30	54,100	47,580	4
Average	30			3
Net Change, F_{tu} at 30^oR				-3.4%
Net Change, F_{ty} at 30^oR				+ 57%
Net Change, Elongation at 30^oR				- 90%

* Samples failed at gross casting defects and indicated values not considered reliable. Only sample 4 Ba 29 used in comparison with room temperature results. Results influenced by casting defects shown in Figure 3.

** Broke outside gage marks.

TABLE 20

TENSILE TEST OF MINIATURE ROUND NOTCHED ALUMINUM ALLOY X-250 SPECIMENS

Alloy	Aluminum X-250	Specification	Vendor
Alloy Code	4 Ba	Heat No.	E 2464A-D
Condition	T-4	Size	0.125" Diameter
Orientation	Longitudinal	Figure No.	1 NR-122

LNP Data

Specimen Number	Test Temp. (°R)	F_{tu} (psi)
4 Ba 15	540	66,700
4 Ba 17	540	65,400
4 Ba 19	540	52,700
4 Ba 20	540	54,000
4 Ba 6	540	54,000
Average	540	58,600
Scatter		23%

TABLE 21

TENSILE TEST OF MINIATURE ROUND ALUMINUM ALLOY B-750 SPECIMENS

Alloy	Aluminum B-750	Specification	Vendor
Alloy Code	6 Ba	Heat No.	Bar No. 301
Condition	T-5	Size	0.125" Diameter
Orientation	Longitudinal	Figure No.	5 ER-5848

LNP Data

Specimen Number	Test Temp. (°R)	F_{tu} (psi)	F_{ty} 0.2% Offset (psi)	Elongation (% in 1/2")
6 Ba 50	540	30,600	20,600	8
6 Ba 64	540	29,800	19,300	12
6 Ba 65	540	28,500	18,700	10
6 Ba 67	540	27,900	17,700	12
6 Ba 68	540	30,060	21,200	10
Average	540	29,400	19,500	10
Scatter		12%	18%	40%
6 Ba 69	30	42,200	24,600	8
6 Ba 71*	30	32,300*	17,500*	*
6 Ba 72	30	45,400	27,600	8
6 Ba 73	30	44,500	26,100	6
6 Ba 76	30	42,400	23,900	8
Average	30	43,600	25,500	8
Scatter		7.3%	14.5%	25%
Net Change, F_{tu} at 30°R				+48%
Net Change, F_{ty} at 30°R				+31%
Net Change, Elongation at 30°R				-20%

* Sample failed at gross casting defect and indicated values not considered reliable. Sample 6 Ba 71 not used in determining average or comparative figures.

TABLE 22

TENSILE TEST OF MINIATURE ROUND NOTCHED
ALUMINUM ALLOY B-750 SPECIMENS

Alloy	Aluminum B-750	Specification	Vendor
Alloy Code	6 Ba	Heat No.	Bar No. 301
Condition	T-5	Size	0.125" Diameter
Orientation	Longitudinal	Figure No.	1 NR-122

LNP Data

Specimen Number	Test Temp. (^oR)	F_{tu} (psi)
6 Ba 5	540	30,900
6 Ba 14	540	29,500
6 Ba 16	540	31,700
6 Ba 33	540	*
6 Ba 43	540	22,300**
Average	540	30,700
Scatter		5.5%
6 Ba 34	30	30,800
6 Ba 44	30	30,800
6 Ba 44	30	33,800
6 Ba 48	30	28,900
6 Ba 53	30	31,000
Average	30	31,000
Scatter	30	16%
Net Change of F_{tu} Tensile Notch at 30^oR		+10%

* Sample failed at gross casting defect in threaded portion.

** Sample considered of questionable reliability due to possibility of micro-porosity influencing results. Not included in determining average or comparative figures.

4.2 NICKEL ALLOYS

The mechanical properties at 540°R and 30°R obtained from the screening program testing of the several nickel alloys are contained in the following tables.

The room temperature (540°R) ultimate tensile strength and 0.2% offset yield strength results for the alloys obtained from the miniature specimens used in this program were in good agreement with the results obtained from Standard ASTM E8-57T specimens and reported in the Pedigree Report (Lockheed Nuclear Products Report ER-5542, February 1962) with a maximum deviation of less than 10% from those reported values.

The test results for the nickel alloys showed close agreement between separate samples of the same alloy with the scatter band for ultimate tensile strength being less than 10% in all cases. The results of the tests are consistent with the published literature available on the properties of nickel alloys at cryogenic temperatures.

The speed of testing was controlled by the speed of the actuating hydraulic pump. The pump speed required to maintain an acceptable test rate was determined by manually marking the stress diagram at 10 second intervals during the portion of the test where the sample exhibited elastic behavior. In the case of tensile testing, the strain rate was held between 0.002 and 0.004 in/in/min, with a frequency of rate checks of approximately 30%. In tensile notch testing, since strain is not recorded, the stress rate was held between 30,000 and 35,000 psi/min with a frequency of rate checks of approximately 25%.

TABLE 23

TENSILE TEST OF MINIATURE ROUND
RENE' 41 SPECIMENS

Alloy	Rene' 41	Specification	Vendor
Alloy Code	7 Ca	Heat No.	R-144
Condition	Solution Treated 1970^{o}, Water Quenched	Size	0.125" Diameter
Orientation	Longitudinal	Figure No.	5 ER-5848

LNP Data

Specimen Number	Test Temp. (^{o}R)	F_{tu} (psi)	F_{ty} 0.2% Offset (psi)	Elongation (% in 1/2")
7 Ca 1	540	128,600	63,200	54
7 Ca 3	540	129,500	*	56
7 Ca 4	540	130,000	62,500	56
7 Ca 5	540	127,500	62,000	56
7 Ca 6	540	130,900	65,000	56
Average	540	129,300	63,200	56
Scatter		2.6%	4.7%	3.6%
7 Ca 10	30	187,400	96,600	**
7 Ca 11	30	193,800	115,000	**
7 Ca 12	30	197,900	111,400	60
7 Ca 13	30	197,800	111,500	61
7 Ca 14	30	193,600	103,500	63
Average	30	194,100	107,600	62
Scatter		5.4%	17 %	5 %
Net Change in F_{tu} at 30^{o}R				+50%
Net Change in F_{ty} at 30^{o}R				+70%
Net Change in Elongation at 30^{o}R				+10.7%

* Malfunction of extensometer, yield data not recorded.

** Fractured faces distorted by compression of sample after failure but before measurement of elongation.

TABLE 24

TENSILE TEST OF MINIATURE ROUND NOTCHED RENE' 41 SPECIMENS

Alloy	Rene' 41	Specification	Vendor
Alloy Code	7 Ca	Heat No.	R-144
Condition	Solution Treated 1970°F	Size	0.125" Diameter
Orientation	Longitudinal	Figure No.	1 NR-122

LNP Data

Specimen Number	Test Temp. (°R)	F_{tu} (psi)
7 Ca 44	540	145,200
7 Ca 45	540	143,100
7 Ca 46	540	141,000
7 Ca 49	540	141,200
7 Ca 50	540	143,800
Average	540	142,900
Scatter		2.9%
7 Ca 52	30	207,800
7 Ca 53	30	201,700
7 Ca 54	30	206,400
7 Ca 55	30	204,000
7 Ca 56	30	202,900
Average	30	204,600
Scatter		3%
Net Change in F_{tu} Tensile Notch at 30°R		+43%

TABLE 25

TENSILE TEST OF MINIATURE ROUND
K-MONEL SPECIMENS

Alloy	K-Monel	Specification	QQ-N-2869
Alloy Code	1 Fb	Heat No.	M-8759-K
Condition	Cold Drawn, Annealed, Age Hardened	Size	0.125" Diameter
Orientation	Longitudinal	Figure No.	5 ER-5848

LNP Data

Specimen Number	Test Temp. (^oR)	F_{tu} (psi)	F_{ty} 0.2% Offset (psi)	Elongation (% in 1/2")
1 Fb 1	540	154,600	97,400	26
1 Fb 2	540	154,900	97,100	26
1 Fb 3	540	154,000	98,100	28
1 Fb 4	540	153,400	97,700	28
1 Fb 5	540	154,000	96,600	26
Average	540	154,200	97,400	26
Scatter		< 1%	1.5%	7.7%
1 Fb 6	30	184,500	121,200	34
1 Fb 7	30	191,000	124,200	34
1 Fb 8	30	192,000	123,200	32
1 Fb 9	30	183,500	118,300	34
1 Fb 11	30	196,600	128,700	36
Average	30	189,500	123,100	34
Scatter	30	6.9%	8.5%	12%
Net Change in F_{tu} at 30^oR				+22.9%
Net Change in F_{ty} at 30^oR				+26.4%
Net Change in Elongation				+30.8%

TABLE 26

TENSILE TEST OF MINIATURE ROUND NOTCHED
K-MONEL SPECIMENS

Alloy	K-Monel	Specification	QQ-N-2869
Alloy Code	1 Fb	Heat No.	M-8759-K
Condition	Cold Drawn, Annealed, Age Hardened	Size	0.125" Diameter
Orientation	Longitudinal	Figure No.	1 NR-122

LNP Data

Specimen Number	Test Temp. (°R)	F_{tu} (psi)
1 Fb 15	540	178,400
1 Fb 17	540	177,200
1 Fb 18	540	178,500
1 Fb 19	540	178,500
1 Fb 20	540	188,700
Average	540	180,300
Scatter		6.4%
1 Fb 22	30	210,200
1 Fb 23	30	210,900
1 Fb 24	30	211,500
1 Fb 25	30	205,500
1 Fb 26	30	210,800
Average	30	209,800
Scatter		2.9%
Net Change in F_{tu} Tensile Notch at 30°R		+10.8%

TABLE 27

TENSILE TEST OF MINIATURE ROUND
INCONEL SPECIMENS

Alloy	Inconel	Specification	MIL-N-6710
Alloy Code	2 Fb	Heat No.	NX-2774
Condition	Cold Drawn	Size	0.125" Diameter
Orientation	Longitudinal	Figure No.	5 ER-5848

LNP Data

Specimen Number	Test Temp. (^oR)	F_{tu} (psi)	F_{ty} 0.2% Offset (psi)	Elongation (% in 1/2")
2 Fb 1	540	138,300	124,500	27
2 Fb 2	540	138,700	130,300	26
2 Fb 3	540	136,200	*	27
2 Fb 4	540	138,100	130,700	28
2 Fb 5	540	139,100	132,800	26
Average	540	138,100	129,600	27
Scatter		2.1%	6.4%	7.4%
2 Fb 7	30	189,300	182,000	28
2 Fb 8	30	191,000	179,800	28
2 Fb 10	30	184,200	166,700	30
2 Fb 77	30	185,400	176,000	24
2 Fb 78	30	181,800	170,700	24
Average	30	186,300	175,000	26
Scatter		4.9%	8.7%	20%
Net Change in F_{tu} at 30^oR				+35%
Net Change in F_{ty} at 30^oR				+35%
Net Change in Elongation				Negligible

* Yield stress not recorded due to malfunction of strain recorder.

TABLE 28

TENSILE TEST OF MINIATURE ROUND NOTCHED INCONEL SPECIMENS

Alloy	Inconel	Specification	MIL-N-6710
Alloy Code	2 Fb	Heat No.	NX-2774
Condition	Cold Drawn	Size	0.125" Diameter
Orientation	Longitudinal	Figure No.	1 NR-122

LNP Data

Specimen Number	Test Temp. (^{o}R)	F_{tu} (psi)
2 Fb 30	540	181,200
2 Fb 31	540	178,500
2 Fb 32	540	180,700
2 Fb 33	540	175,600
2 Fb 34	540	178,400
Average	540	178,900
Scatter		3.1%
2 Fb 70	30	222,600
2 Fb 71	30	212,800
2 Fb 72	30	226,500
2 Fb 73	30	226,500
2 Fb 74	30	225,200
Average	30	222,700
Scatter		6.2%
Net Change in F_{tu} Tensile Notch at 30^{o}R		+24.5%

4.3 STAINLESS STEEL ALLOYS

The mechanical properties at 540°R and 30°R obtained from the screening program testing of the several stainless steel alloys are contained in the following tables.

The room temperature (540°R) ultimate tensile strength and 0.2% offset yield strength results for these alloys obtained for the miniature specimens used in this program had a maximum variance of 20% with the Standard ASTM E8-57T specimens reported in the Pedigree Report (Lockheed Nuclear Products Report ER-5542, February 1962) for the same lots of material and an average deviation of 11-1/2%.

The test results for the stainless steel alloys showed satisfactory agreement between separate samples of the same alloy with an average divergency of less than 10% for the several sets of samples.

The speed of testing was controlled by the speed of the actuating hydraulic pump. The pump speed required to maintain an acceptable test rate was determined by manually marking the stress diagram at 10 second intervals during the portion of the test where the sample exhibited elastic behavior. In the case of tensile testing, the strain rate was held between 0.002 and 0.005 in/in/min, with a frequency of rate checks of approximately 30%. In tensile notch testing, since strain is not recorded, the stress rate was held between 30,000 and 80,000 psi/min with a frequency of rate checks of approximately 10%. A higher incidence of rate control checks is planned for in-pile tensile notch samples.

TABLE 29

TENSILE TEST OF MINIATURE ROUND
AISI-304 SPECIMENS

Alloy	AISI-304	Specification	ASTM-A-167-58
Alloy Code	2 Cb	Heat No.	801904
Condition	Annealed	Size	0.125" Diameter
Orientation	Longitudinal	Figure No.	5 ER-5848

LNP Data

Specimen Number	Test Temp. (^oR)	F_{tu} (psi)	F_{ty} 0.2% Offset (psi)	Elongation (% in 1/2")
2 Cb 97	540	96,300	37,500	78
2 Cb 207	540	95,200	35,600	80
2 Cb 212	540	95,300	36,400	80
2 Cb 241	540	95,600	36,600	80
2 Cb 214	540	93,500	37,800	80
Average	540	95,200	36,800	80
Scatter		2.9%	5%	25%
2 Cb 215	30	243,700	40,300	38
2 Cb 218	30	269,800	46,800	38
2 Cb 220	30	214,500	*	38
2 Cb 234	30	232,100	43,100	34
2 Cb 238	30	248,700	42,900	30
Average	30	239,800	42,700	36
Scatter		23%	15%	22%
Net Change in F_{tu} at 30°R				+150%
Net Change in F_{ty} at 30°R				+ 16%
Net Change in Elongation				- 55%

* Extensometer jaws slipped on specimen and gave inaccurate strain readings.

TABLE 30

TENSILE TEST OF MINIATURE ROUND NOTCHED AISI-304 SPECIMENS

Alloy	AISI-304	Specification	ASTM-A-167-58
Alloy Code	2 Cb	Heat No.	801904
Condition	Annealed	Size	0.125" Diameter
Orientation	Longitudinal	Figure No.	1 NR-122

LNP Data

Specimen Number	Test Temp. (^{o}R)	F_{tu} (psi)
2 Cb 95	540	99,720
2 Cb 211	540	104,000
2 Cb 216	540	111,400
2 Cb 222	540	109,990
Average	540	106,300
Scatter		10%
2 Cb 233	30	163,100
2 Cb 235	30	189,700
2 Cb 244	30	166,700
2 Cb 246	30	150,700
Average	30	167,600
Scatter		23.3%
Net Change in F_{tu} Tensile Notch at $30^{o}R$		+57%

TABLE 31

TENSILE TEST OF MINIATURE ROUND
AISI-310 SPECIMENS

Alloy	AISI 310	Specification	ASTM-A-167-58
Alloy Code	3 Cb	Heat No.	X-48 576
Condition	Annealed	Size	0.125" Diameter
Orientation	Longitudinal	Figure No.	5 ER-5848

LNP Data

Specimen Number	Test Temp. (^{o}R)	F_{tu} (psi)	F_{ty} 0.2% Offset (psi)	Elongation (% in 1/2")
3 Cb 4	540	78,600	60,400	*
3 Cb 5	540	82,800	61,300	46
3 Cb 15	540	84,900	58,900	*
3 Cb 32	540	87,000	63,500	*
3 Cb 33	540	91,300	68,400	*
Average	540	84,900	62,500	46
Scatter		15%	15.2%	

* Fractured faces damaged by compressing specimen after failure but before measurement of elongation.

TABLE 32

TENSILE TEST OF MINIATURE ROUND NOTCHED AISI-310 SPECIMENS

Alloy	AISI-310	Specification	ASTM-A-167-58
Alloy Code	3 Cb	Heat No.	X-48 576
Condition	Annealed	Size	0.125" Diameter
Orientation	Longitudinal	Figure No.	1 NR-122

LNP Data

Specimen Number	Test Temp. (^oR)	F_{tu} (psi)
3 Cb 16	540	110,500
3 Cb 17	540	111,700
3 Cb 18	540	112,100
3 Cb 19	540	111,900
3 Cb 20	540	111,400
Average	540	111,500
Scatter		1.4%
3 Cb 23	30	161,600
3 Cb 24	30	159,300
3 Cb 25	30	163,200
3 Cb 26	30	161,600
Average	30	161,400
Scatter		2.4%
Net Change in F_{tu} Tensile Notch at 30^oR		+45%

TABLE 33

TENSILE TEST OF MINIATURE ROUND
AISI-347 SPECIMENS

Alloy	AISI-347	Specification	ASTM-A-167-58
Alloy Code	4 Cb	Heat No.	X-45 779
Condition	Annealed	Size	0.125" Diameter
Orientation	Longitudinal	Figure No.	5 ER-5848

LNP Data

Specimen Number	Test Temp. (^{o}R)	F_{tu} (psi)	F_{ty} 0.2% Offset (psi)	Elongation (% in 1/2")
4 Cb 2	540	93,900	44,300	58
4 Cb 5	540	94,900	43,600	58
4 Cb 6	540	94,800	43,700	58
4 Cb 7	540	93,900	46,300	58
4 Cb 9	540	94,400	46,800	56
Average	540	94,400	44,900	58
Scatter		1%	7.8%	3.4%
4 Cb 30	30	233,500	58,200	44
4 Cb 31	30	243,900	47,800	42
4 Cb 32	30	234,800	51,200	38
4 Cb 33	30	242,800	52,200	*
4 Cb 34	30	233,800	51,800	44
Average	30	237,700	52,200	42
Scatter		3.9%	20%	14%
Net Change in F_{tu} at 30^{o}R				+151%
Net Change in F_{ty} at 30^{o}R				+16%
Net Change in Elongation at 30^{o}R				-27%

* Specimen damaged after testing but prior to removal from specimen holder.

TABLE 34

TENSILE TEST OF MINIATURE ROUND NOTCHED AISI-347 SPECIMENS

Alloy	AISI-347	Specification	ASTM-A-167-58
Alloy Code	4 Cb	Heat Not.	X-45 779
Condition	Annealed	Size	0.125" Diameter
Orientation	Longitudinal	Figure No.	1 NR-122

LNP Data

Specimen Number	Test Temp. (°R)	F_{tu} (psi)
4 Cb 15	540	118,900
4 Cb 16	540	108,300
4 Cb 17	540	110,000
4 Cb 18	540	118,900
4 Cb 19	540	108,700
Average	540	112,900
Scatter		9.4%
4 Cb 21	30	230,900
4 Cb 22	30	230,000
4 Cb 23	30	220,700
4 Cb 24	30	226,900
Average	30	227,000
Scatter	30	4.5%
Net Change in F_{tu} Tensile Notch at 30°R		+100%

TABLE 35

TENSILE TEST OF MINIATURE ROUND
TYPE A-286 SPECIMENS

Alloy	A-286	Specification	AMS-5735-E (Mod)
Alloy Code	6 Ca	Heat No.	K-46419
Condition	Solution Treated	Size	0.125" Diameter
Orientation	Longitudinal	Figure No.	5 ER-5848

LNP Data

Specimen Number	Test Temp. (^{o}R)	F_{tu} (psi)	F_{ty} 0.2% Offset (psi)	Elongation (% in 1/2")
6 Ca 1	540	156,700	115,700	24
6 Ca 2	540	158,800	111,000	26
6 Ca 3	540	157,600	113,100	26
6 Ca 4	540	152,800	110,800	26
6 Ca 5	540	154,300	110,000	26
Average	540	155,900	112,000	26
Scatter		3.8%	5.1%	7%
6 Ca 6	30	265,700	151,700	36
6 Ca 7	30	229,500	147,800	38
6 Ca 8	30	230,700	147,900	36
6 Ca 9	30	222,200	142,400	36
6 Ca 10	30	225,900	144,900	36
Average	30	235,000	147,000	36
Scatter		18.5%	6.3%	5.6%

TABLE 36

TENSILE TEST OF MINIATURE ROUND NOTCHED
TYPE A-286 SPECIMENS

Alloy	A-286	Specification	AMS-5735-E (Mod)
Alloy Code	6 Ca	Heat No.	K-46419
Condition	Solution Treated	Size	0.125" Diameter
Orientation	Longitudinal	Figure No.	1 NR-122

LNP Data

Specimen Number	Test Temp. (°R)	F_{tu} (psi)
6 Ca 33	540	178,800
6 Ca 36	540	181,500
6 Ca 37	540	181,700
6 Ca 38	540	179,500
6 Ca 39	540	182,300
Average	540	181,000
Scatter		2%
6 Ca 49	30	208,900
6 Ca 50	30	202,100
6 Ca 51	30	215,700
6 Ca 52	30	220,300
6 Ca 53	30	233,900
Average	30	216,000
Scatter		14.7%
Net Change in F_{tu} Tensile Notch at 30°R		+ 19%

TABLE 37

TENSILE TEST OF MINIATURE ROUND
TYPE A-353 SPECIMENS

Alloy	A-353	Specification	ASTM-A-353-58
Alloy Code	5 Ca	Heat No.	16156
Condition	Normalized, Air Cooled	Size	0.125" Diameter
Orientation	Longitudinal	Figure No.	5 ER-5848

LNP Data

Specimen Number	Test Temp. (°R)	F_{tu} (psi)	F_{ty} 0.2% Offset (psi)	Elongation (% in 1/2")
5 Ca 1	540	111,500	91,500	24
5 Ca 2	540	112,800	88,000	22
5 Ca 3	540	110,400	85,600	24
5 Ca 4	540	109,900	88,600	24
5 Ca 5	540	109,200	86,600	24
Average	540	111,000	88,000	24
Scatter		3.2%	6.7%	10%
5 Ca 7	30	228,200	170,100	20
5 Ca 8	30	203,600	173,900	18
5 Ca 9	30	199,500	167,700	20
5 Ca 10	30	196,900	172,200	22
5 Ca 11	30	203,400	182,500	*
Average	30	206,300	175,000	20
Scatter		15%	8.4%	20%
Net Change, F_{tu} at 30°R				+85%
Net Change, F_{ty} at 30°R				+98.8%
Net Change, Elongation at 30°R				-20%

* Out of gage.

TABLE 38

TENSILE TEST OF MINIATURE ROUND NOTCHED TYPE A-353 SPECIMENS

Alloy	A-353	Specification	ASTM-A-353-58
Alloy Code	5 Ca	Heat No.	16156
Condition	Normalized, Air Cooled	Size	0.125" Diameter
Orientation	Longitudinal	Figure No.	1 NR-122

LNP Data

Specimen Number	Test Temp. (^oR)	F_{tu} (psi)
5 Ca 49	540	137,100
5 Ca 50	540	137,400
5 Ca 51	540	136,700
5 Ca 52	540	136,300
5 Ca 53	540	135,500
Average	540	136,600
Scatter		1.3%
5 Ca 55	30	205,130
5 Ca 57	30	179,550
5 Ca 60	30	182,710
5 Ca 61	30	174,840
Average	30	185,600
Scatter		1.6%
Net Change in F_{tu} Tensile Notch at 30^oR		+36%

4.4 TITANIUM ALLOYS

The mechanical properties at 540°R and 30°R obtained from the screening program testing of the several titanium alloys are contained in the following tables.

The room temperature (540°R) ultimate tensile strength and 0.2% offset yield strength results for the alloys obtained from the miniature specimens used in this program were within a 20% scatter band with the results obtained from Standard ASTM E8-57T specimens reported in the Pedigree Report (Lockheed Nuclear Products Report ER-5542, February 1962).

Some difficulty was encountered in testing those titanium alloys in which the yield strength approaches the tensile strength at 30°R due to extensometer slippage during elastic deformation altering the modulus slope of the stress-strain curve. The yield strength values obtained from 4 of the 5 samples tested at 30°R for Titanium Alloy 5Al-2.5Sn annealed were discarded for this reason. The yield strength values reported at 30°R for Titanium Alloy 6Al-4V, solution treated and aged, were obtained by projection of an appreciable portion of the stress-strain curve in which the slope was in agreement with published values for Young's modulus of elasticity at cryogenic temperatures and should not be considered absolute values. The yield strength values at 30°R for two samples of Titanium 6Al-4V, annealed, were obtained in the same manner and included only for comparison. Extensometer manipulation techniques to prevent reccurence of this during in-pile testing have been tentatively adopted but cannot be proven until testing is resumed.

The speed of testing was controlled by the speed of the actuating hydraulic pump. The pump speed required to maintain an acceptable test rate was determined by manually marking the stress diagram at 10 second intervals during the portion of the test where the sample exhibited elastic behavior. In the case of tensile testing, the strain rate was held between 0.003 and 0.005 in/in/min, with a frequency of rate checks of approximately 30%. In tensile notch testing, since strain is not recorded, the stress rate was held between 65,000 and 95,000 psi/min with a frequency of rate checks of approximately 25%.

TABLE 39

TENSILE TEST OF MINIATURE ROUND TITANIUM 55A SPECIMENS

Alloy	Titanium 55 A	Specification	MIL-7-7993A Class II
Alloy Code	1 Aa	Heat No.	M-9186
Condition	Annealed	Size	0.125" Diameter
Orientation	Longitudinal	Figure No.	5 ER-5848

LNP Data

Specimen Number	Test Temp. (^{o}R)	F_{tu} (psi)	F_{ty} 0.2% Offset (psi)	Elongation (% in 1/2")
1 Aa 126	540	66,600	55,500	30
1 Aa 139	540	69,300	63,500	26
1 Aa 155	540	66,800	51,200	32
1 Aa 157	540	65,100	47,500	32
1 Aa 158	540	66,700	50,500	32
Average	540	66,900	53,600	30
Scatter		6.3%	30 %	20%
1 Aa 160	30	171,200	123,800	34
1 Aa 191	30	166,600	118,000	32
1 Aa 192	30	171,200	123,800	32
1 Aa 193	30	166,800	118,500	32
1 Aa 194	30	170,000	123,800	34
Average	30	169,200	121,600	33
Scatter		2.7%	4.8%	6 %
Net Change, F_{tu} at 30^{o}R				+168%
Net Change, F_{ty} at 30^{o}R				+127%
Net Change, Elongation at 30^{o}R				+ 10%

TABLE 40

TENSILE TEST OF MINIATURE ROUND NOTCHED TITANIUM 55A SPECIMENS

Alloy	Titanium 55A	Specification	MIL-7-7993A Class II
Alloy Code	1 Aa	Heat No.	M-9186
Condition	Annealed	Size	0.125" Diameter
Orientation	Longitudinal	Figure No.	1 NR-122

LNP Data

Specimen Number	Test Temp. (°R)	F_{tu} (psi)
1 Aa 130	540	81,300
1 Aa 131	540	82,700
1 Aa 133	540	84,100
1 Aa 134	540	86,400
1 Aa 135	540	86,900
Average	540	84,300
Scatter		6.6%
1 Aa 137	30	161,100
1 Aa 140	30	167,700
1 Aa 141	30	157,400
1 Aa 146	30	166,900
1 Aa 147	30	179,000
Average	30	166,400
Scatter		13%
Net Change in F_{tu} Tensile Notch at 30°R		+ 97%

TABLE 41

TENSILE TEST OF MINIATURE ROUND TITANIUM-5Al-2.5Sn SPECIMENS

Alloy	Titanium-5Al-2.5Sn	Specification	AMS-4910
Alloy Code	3 Aa	Heat No.	M-7888
Condition	Annealed	Size	0.125" Diameter
Orientation	Longitudinal	Figure No.	5 ER-5848

LNP Data

Specimen Number	Test Temp. (°R)	F_{tu} (psi)	F_{ty} 0.2% Offset (psi)	Elongation (% in 1/2")
3 Aa 15	540	124,000	121,500	24
3 Aa 16	540	125,800	114,200	24
3 Aa 17	540	123,300	112,600	24
3 Aa 18	540	120,900	108,900	24
3 Aa 19	540	120,600	107,600	24
Average	540	122,900	112,900	24
Scatter		4.2%	12.3%	0
3 Aa 29	30	225,300	215,600	14
3 Aa 30	30	224,900	*	12
3 Aa 31	30	221,200	*	14
3 Aa 32	30	223,600	*	14
3 Aa 33	30	222,800	*	20
Average	30	223,600	215,600	15
Scatter		2%	-	40%
Net Change, F_{tu} at 30°R				+ 80%
Net Change, F_{ty} at 30°R				+ 90%
Net Change, Elongation at 30°R				- 37%

* Extensometer slippage distorted modulus slope on stress-strain diagram so strain determination from curve insufficiently reliable to report yield strength of material.

TABLE 42

TENSILE TEST OF MINIATURE ROUND NOTCHED TITANIUM-5Al-2.5Sn SPECIMENS

Alloy	Titanium-5Al-2.5Sn	Specification	AMS-4910
Alloy Code	3 Aa	Heat No.	M-7888
Condition	Annealed	Size	0.125" Diameter
Orientation	Longitudinal	Figure No.	1 NR-122

LNP Data

Specimen Number	Test Temp. (^{o}R)	F_{tu} (psi)
3 Aa 1	540	168,000
3 Aa 2	540	169,200
3 Aa 3	540	166,600
3 Aa 4	540	164,100
3 Aa 5	540	167,000
Average	540	166,900
Scatter		3%
3 Aa 7	30	257,500
3 Aa 8	30	258,400
3 Aa 9	30	246,700
3 Aa 10	30	247,000
3 Aa 11	30	245,900
Average	30	251,100
Scatter		5%
Net Change, F_{tu} Tensile Notch at 30^{o}R		+50%

TABLE 43

TENSILE TEST OF MINIATURE ROUND TITANIUM-6Al-4V SPECIMENS

Alloy	Titanium-6Al-4V	Specification	MIL-T-9047-C
Alloy Code	2 Ac	Heat No.	M-8574
Condition	Annealed	Size	0.125" Diameter
Orientation	Longitudinal	Figure No.	5 ER-5848

LNP Data

Specimen Number	Test Temp. (^oR)	F_{tu} (psi)	F_{ty} 0.2% Offset (psi)	Elongation (% in 1/2")
2 Ac 6	540	143,900	139,400	14
2 Ac 2	540	144,800	140,200	12
2 Ac 3	540	144,900	139,500	14
2 Ac 4	540	141,700	132,600	14
2 Ac 5	540	145,100	140,500	12
Average	540	144,100	138,400	13
Scatter		2.4%	5.7%	15%
2 Ac 7	30	264,400	*	6
2 Ac 8	30	263,300	239,800	6
2 Ac 9	30	263,900	230,600	4
2 Ac 10	30	260,500	250,000**	6
2 Ac 12	30	252,000	243,000**	6
Average	30	260,800	235,200	6
Scatter		4.7%	8%	33%
Net Change in F_{tu} at 30^oR				+80%
Net Change in F_{ty} at 30^oR				+69%
Net Change in Elongation				-54%

* Extensometer slipped and stopped recording below yield strength.

** Values obtained by projection of a portion of the stress-strain curve and included only for comparison. Not included in average values or net change.

TABLE 44

TENSILE TEST OF MINIATURE ROUND NOTCHED TITANIUM-6Al-4V SPECIMENS

Alloy	Titanium-6Al-4V	Specification	MIL-T-9047C
Alloy Code	2 Ac	Heat No.	M-8574
Condition	Annealed	Size	0.125" Diameter
Orientation	Longitudinal	Figure No.	1 NR-122

LNP Data

Specimen Number	Test Temp. (°R)	F_{tu} (psi)
2 Ac 15	540	185,800
2 Ac 16	540	182,900
2 Ac 17	540	184,100
2 Ac 18	540	182,900
2 Ac 19	540	187,000
Average	540	184,500
Scatter		2.2%
2 Ac 21	30	276,600
2 Ac 22	30	289,300
2 Ac 23	30	272,500
2 Ac 26	30	277,400
2 Ac 27	30	286,600
Average	30	280,500
Scatter		6%
Net Change, F_{tu} Tensile Notch at 30°R		+52%

TABLE 45

TENSILE TEST OF MINIATURE ROUND TITANIUM-6Al-4V SPECIMENS

Alloy	Titanium-6Al-4V	Specification	MIL-T-9047-C
Alloy Code	2 Aa	Heat No.	M-9812
Condition	Solution Treated & Aged at 1000°F, Air Cooled	Size	0.125" Diameter
Orientation	Longitudinal	Figure No.	5 ER-5848

LNP Data

Specimen Number	Test Temp. (°R)	F_{tu} (psi)	F_{ty} 0.2% Offset (psi)	Elongation (% in 1/2")
2 Aa 2	540	170,000	160,500	16
2 Aa 3	540	168,400	161,400	16
2 Aa 4	540	167,600	155,100	16
2 Aa 5	540	169,800	160,000	16
2 Aa 7	540	160,900	155,900	18
Average	540	167,300	158,600	16
Scatter		5.4%	3.9%	12.5%
2 Aa 10	30	284,100	277,000*	4
2 Aa 11	30	287,800	285,500*	4
2 Aa 12	30	281,100	273,000*	4
2 Aa 13	30	282,800	278,000*	4
2 Aa 29	30	283,300	270,000*	4
Average	30	283,800	276,700*	4
Scatter		2.4%	5.6%	0
Net Change in F_{tu} at 30°R				+70%
Net Change in F_{ty} at 30°R				+74%*
Net Change in Elongation at 30°R				-75%

* Values obtained by projection of a portion of stress-strain curve and should be used for comparison only.

TABLE 46

TENSILE TEST OF MINIATURE ROUND NOTCHED TITANIUM-6Al-4V SPECIMENS

Alloy	Titanium-6Al-4V	Specification	MIL-T-9047-C
Alloy Code	2 Aa	Heat No.	M-9812
Condition	Solution Treated & Aged at 1000°F, Air Cooled	Size	0.125" Diameter
Orientation	Longitudinal	Figure No.	1 NR-122

LNP Data

Specimen Number	Test Temp. (°R)	F_{tu} (psi)
2 Aa 60	540	201,900
2 Aa 61	540	199,400
2 Aa 62	540	200,600
2 Aa 63	540	204,600
2 Aa 64	540	203,100
Average	540	201,900
Scatter		2.6%
2 Aa 67	30	283,100
2 Aa 68	30	287,200
2 Aa 69	30	289,200
2 Aa 70	30	290,900
2 Aa 71	30	291,200
Average	30	288,300
Scatter		2.8%
Net Change in F_{tu} at 30°R		+43%

TABLE 47

TENSILE TEST OF MINIATURE ROUND TITANIUM-8Al-1Mo-1V SPECIMENS

Alloy	Titanium-8Al-1Mo-1V	Specification	Vendor
Alloy Code	4 Aa	Heat No.	V-1306
Condition	Annealed and Aged	Size	0.125" Diameter
Orientation	Longitudinal	Figure No.	5 ER-5848

LNP Data

Specimen Number	Test Temp. (^oR)	F_{tu} (psi)	F_{ty} 0.2% Offset (psi)	Elongation (% in 1/2")
4 Aa 6	540	133,700	130,200	22.0
4 Aa 7	540	140,100	134,800	22.0
4 Aa 8	540	140,100	136,100	22.0
4 Aa 51	540	*	*	22.0
4 Aa 52	540	*	*	20.0
Average	540	137,900	133,700	22.0
Scatter		4.6%	4.4%	10%
4 Aa 1	30	245,100	226,300	5.8
4 Aa 2	30	250,700	242,300	15.2
4 Aa 3	30	243,600	223,100	12.1
4 Aa 4	30	242,900	230,800	7.8
4 Aa 5	30	244,600	230,200	7.8
Average	30	245,400	230,500	9.5**
Scatter		3%	6.9%	97%**
Net Change in F_{tu} at 30^oR				+78%
Net Change in F_{ty} at 30^oR				+72%
Net Change in Elongation at 30^oR				**

* Inspection data unavailable so original diameter of specimen unknown.

** Due to the high scatter of the 30^oR elongation values, comparisons are shown in Figure 4.

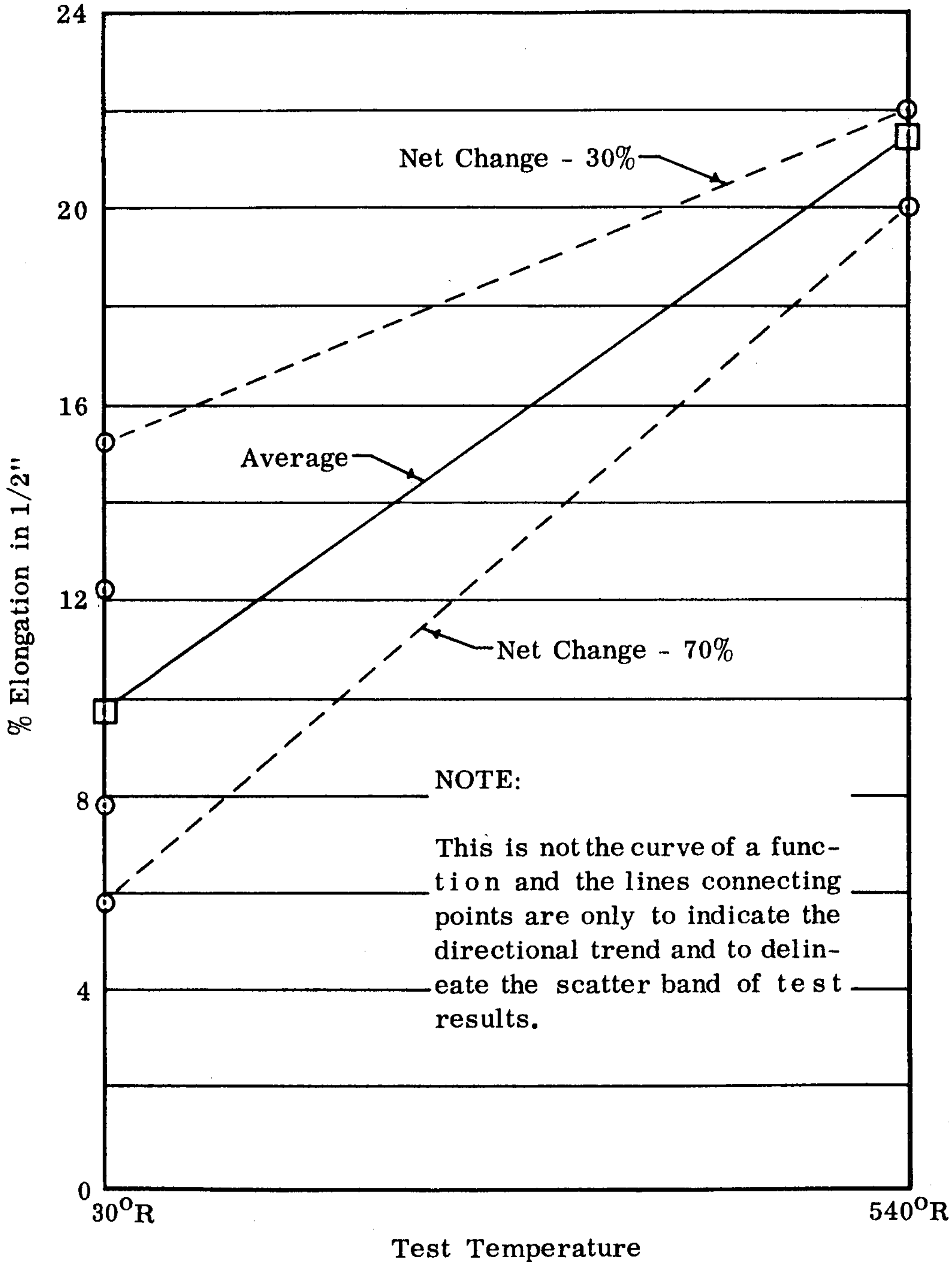


FIGURE 4 TENSILE TEST MINIATURE ROUND TITANIUM 8Al-1Mo-1V SPECIMENS

TABLE 48

TENSILE TEST OF MINIATURE ROUND NOTCHED TITANIUM-8Al-1Mo-1V SPECIMENS

Alloy	Titanium-8Al-1Mo-1V	Specification	Vendor
Alloy Code	4 Aa	Heat No.	V-1306
Condition	Annealed and Aged	Size	0.125" Diameter
Orientation	Longitudinal	Figure No.	1 NR-122

LNP Data

Specimen Number	Test Temp. (°R)	F_{tu} (psi)
4 Aa 17	540	170,800
4 Aa 19	540	173,100
4 Aa 20	540	176,200
4 Aa 21	540	172,100
4 Aa 22	540	171,300
Average	540	172,700
Scatter		3.1%
4 Aa 23	30	258,600
4 Aa 25	30	279,900
4 Aa 27	30	260,600
4 Aa 28	30	272,000
4 Aa 29	30	271,800
Average	30	268,600
Scatter	30	7.9%
Net Change, F_{tu} at 30°R		+55.5%

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